InP 2D Nano-Hole Arrays Fabricated by Two Times Laser Holography

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1. Introduction: Photonic crystals (PC) have been drawing great attention in recent years for its unique characteristics and many ways of application such as reflectors, spectral filters, laser resonators, and waveguides. In order to realize practical PC's in optical regions, fabrication of periodically aligned pattern in submicrometer order is extremely essential. So far, a number of results have been reported to fabricate photonic band gap structures using electron beam lithography. To cover large area of a substrate with these patterns, electron beam lithography would be rather inefficient compared to using laser beam holography, which is capable for large area exposure.[1] In this paper, we show the fabrication of InP 2D nano-hole arrays by two times laser holography with a post-etching process to make the holes homogeneous. After the processes, we measured the reflectivity to observe their peculiar optical characteristics.

2. Experiment: Figure 1 shows the schematic of two times laser holography. First, an InP substrate with photoresist (THMR-ip3300; Tokyo Ohka Kogyo Co., Ltd.) was set by aligning its orientation relative to the fringe direction with a proper mirror angle θ for a designed period, and was exposed to the expanded He-Cd laser-beams (the wavelength: 325nm) photoresist (THMR-ip3300; Tokyo Ohka Kogyo Co., Ltd.). We then rotated the stage for an arbitrary angle ϕ and once again exposed the substrate with interference fringes to complete two times laser holography. After the development of the pattern with 2.38% NMD-3 (Tokyo Ohka Kogyo Co., Ltd.), the sample was wet-etched with $HBr:HNO_3:H_2O$=1:1:10 solution for 10 seconds at room temperature. As a post-etching process, the etched substrate was rinsed with acetone to remove the photoresist, then was dipped in the HF (50wt%) for 24, 48, and 120 hours at room temperature to unify the shapes of 2D nano-holes.

3. Result: Figure 2(a) shows a scanning electron microscope (SEM) image of the surface of the fabricated (100) InP etched substrate. The period of the pattern was set to be 500nm and the rotation angle was 60 degrees forming a triangular lattice. The holes are positioned in periodically, but their shapes seem to be not identical. Figure 2(b), (c), and (d) are SEM images of the substrates after the post-etching process in HF solution for 24, 48, and 120 hours, respectively. We can see that the longer we left the substrate in HF solution, the more identical the shapes of the holes became. This is because of the anisotropic etching of the (100) InP surface with HF solution.[2] Even though the holes got larger as the time of etching got longer, the period of the pattern remains at about 500nm. This shows that the post etching process by HF solution is an appropriate approach to make uniformly shaped and aligned patterns.

Figure 3 shows reflection ratios of the patterned InP surfaces with various etching time by HF solution to the flat InP surface, measured by shining the light from a normal direction with an objective lens. Here, instead of the wet etching as the first-etching, we milled the substrates by Ar^{3+} ion beam, and then dipped them in HF solution. Though the first etching was different, eventually we obtained the same etching results. We can see that the reflectivity increased as the etching time increased. It seems to be attributed to that average flatness of the sample increased with longer etching time, as can be seen from Fig. 2(a)-(d) as a result of the decrease of scattering from the sample. We can also see dips in the reflection spectra at around 1μm wavelength. This may also be caused by the periodical structures, and this discussion needs more considerations.

4. Conclusion: We showed the fabrication of 2D nano-hole arrays on InP substrates by two times laser holography. We were able to make the holes identical by dipping the substrates in HF solution. Reflectivity from the substrate depended on the etching time by HF solution, and observed spectral dips around 1μm. These substrates are promising for applications to surface-reflectivity controlled photonic devices.

5. References:

[1]T.A.Savas, et al.: J. Vac. Sci. Technol., B, **14**, 4167(1996)
[2]M. Nakao, et al.: Jpn. J. Appl. Phys., **38**, Pt.1, No.2B, 1055(1999)

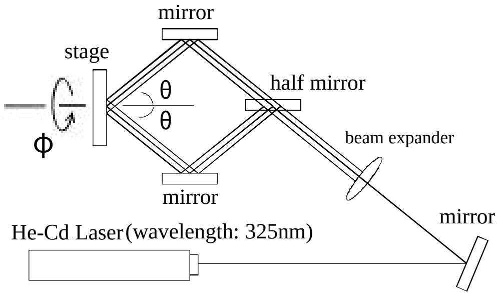

Figure 1. Schematic of laser holography

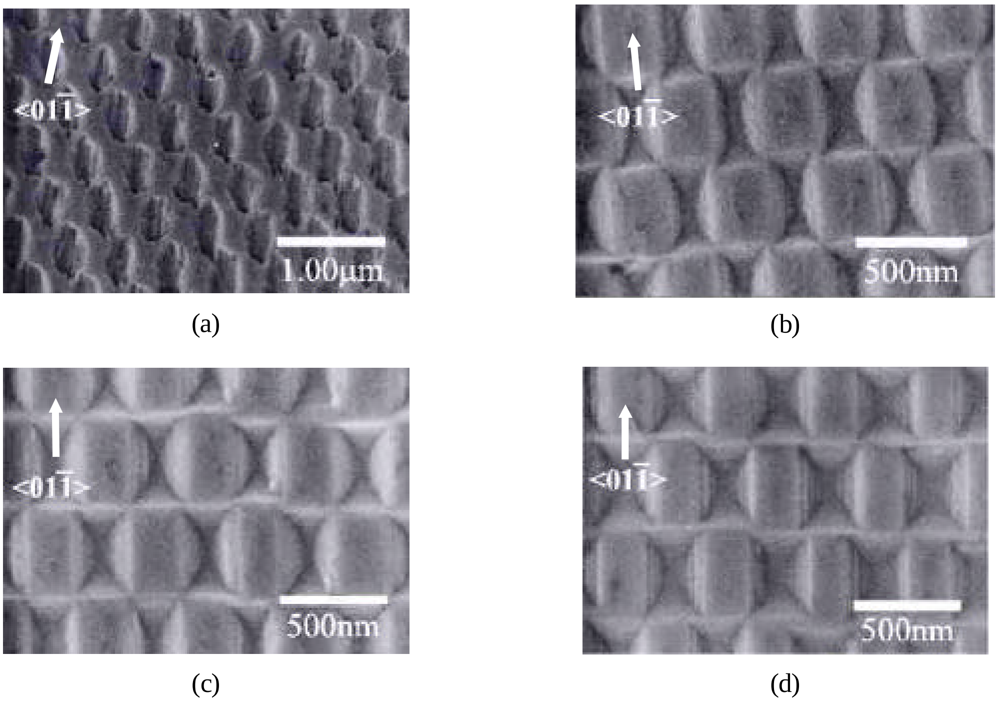

Figure 2. SEM images of the surface of the fabricated (100) InP etched substrates after (a)wet etching and HF etching for (b)24 hours, (c) 48 hours, and (d) 120 hours

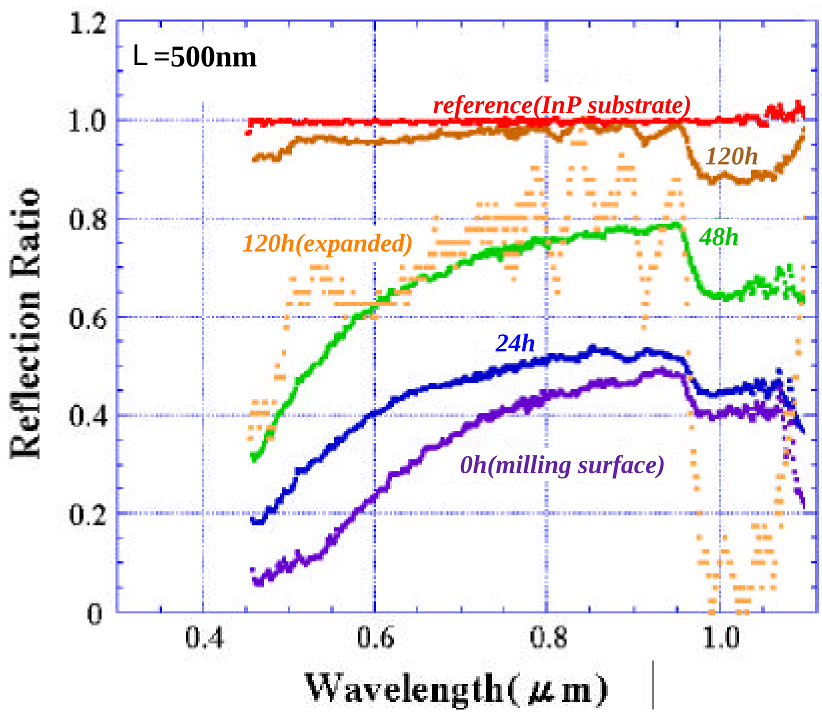

Figure 3. Reflection ratios of the patterned InP surfaces with various etching time by HF solution to the flat InP surface